Readjustment of the Channel Gradient of Dry Creek in Licking County, Ohio

by

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Abstract. Sand and gravel reserves in formerly glaciated regions of the northern United States are great. The practice of mining these resources from buried channels of glacial meltwater streams, oxbows or meander cutoffs has been quite profitable. Environmental effects of these mining operations are minimal in comparison with the effects produced through the excavation of other resources throughout the country. Although more wasteful, mining methods of dredging flowing stream channels, settlement pits within channels and rechannelization of streams may likely produce extensive erosional damage to the local drainage basin over a period of years. The effects of erosion stemming from these mining procedures are absorbed by an array of individuals. Property values decline which may effect not only the individual but also the neighborhood or town, bridges may become unstable due to changes in channel width or depth, and even roads and power lines may have to be relocated at the expense of taxpayers and consumers.

This report is a somewhat subjective investigation concerning the ongoing erosive damage to the channel of Dry Creek

in Licking County, Ohio, resulting from the aforementioned mining procedures. Because of the expense and the length of time needed, a more quantitative and comprehensive experimental study was not undertaken. The results of this report will come through a small number of actual measurements but more importantly through the collaborative results of former investigations which may be related to the problem at hand. In particular this report will relate the values of stream competence at maximum discharge with the effects of natural channel armouring, bank erosion and changes in channel geometry. These changes are the result of human stress applied to the equilibrium basis of the graded stream system.

INTRODUCTION

The following is an analysis of the ability of a stream to return to a condition of equilibrium following the extensive impact of the work of man which has interfered with the natural progression of the graded stream. In a specific case, the profligate practice of gravel mining within stream channels has profoundly altered the equilibrium of Dry Creek in Licking County, Ohio, resulting in unusually extensive erosional damage to the local drainage basin. Due to the unconsolidated nature of the channel material these alterations in channel geometry have developed over a relatively short period of time.

A graded stream is one in which, over a period of years, slope and channel characteristics are delicately adjusted to provide, with available discharge, just the velocity required for the transportation of the load supplied from the drainage basin. The graded stream is a system in equilibrium, its diagnostic characteristic is that any change in any of the controlling factors will cause a displacement of the equilibrium in a direction that will tend to absorb the effect of the change (Leopold and Maddock, 1953). A graded stream responds to change in conditions in accordance with Le Chatelier's general law: "if a stress is brought to bear on a system in equilibrium, a reaction occurs, displacing the equilibrium in a direction that tends to absorb the effect of the stress." Readjustment is effected primarily by appropriate modification of slope by upbuilding or downcutting, and only to a minor extent or not at all by concomitant changes in channel characteristics (Mackin, 1948). In the study of the channel of Dry Creek it is believed that the lowering of the local base level downstream from the Finney farm is so dramatic that stream competence is not sufficient to "appropriately modify" the slope through downcutting and thus has developed major changes in channel characteristics through amplified erosional processes.

The procedure of sand and gravel mining within the channel of Dry Creek which began in the late '40's is quite simple. A large pit is dug in the channel which is allowed to fill with sediment from the stream. Dredging of the pit is usually seasonal, after periods of high discharge within the channel. The erosive effects of mining can be seen by comparing aerial photos of the area both before and after mining began. Aerial photos are available from the Ohio Department of Transportation and the U.S.D.A. - Soil Conservation Service. From the photos dated prior to mining, Dry Creek can be described as a gently meandering, intermittent stream which entered the Finney property near the northwest corner and flowed to the east and northeast towards the North Fork of the Licking River where a small railroad bridge underpass at State Route 13 forms the local base level for the stream. After mining began a new local base level was formed by the sediment pits located between the bridge underpass and the Finney farm which caused the stream gradient to increase, thus producing an increase in the energy of the stream. This energy increase resulted in the erosive effects which can clearly be seen from the post mining aerial photos. As mining continued, channel erosion propagated upstream. From estimates by H.R. Finney it was not until approximately 1962 when significant erosion was observed in the channel on the Finney farm. Total land losses from 1962 until 1983 were estimated by H.R. Finney as a minimum of 2.16 acres of land and 159,986 tons of material.

As mining has continued until the present date in the Dry Creek channel, the energy of the stream has never attained equilibrium. The potential energy produced by dredging the channel has been greater than the energy needed to transport the sediment load from the drainage basin. The procedure of channel mining seen at Dry Creek is a presidential account which supports the concept of the graded river quoted earlier. In review, this quote can be applied to the events at Dry Creek as follows: its (the graded river) diagnostic characteristic is that any change in any of the controlling factors (gradient, channel geometry, etc.) will cause a displacement of the equilibrium (energy) in a direction that will tend to absorb the effect of the change (erosion).

Now that the recent history of Dry Creek has been presented, the author of this paper would like to proceed with his investigation. The study of Dry Creek is very interesting to the hydrologist or the engineer because the stream flows across material which is unconsolidated (glacial outwash) and which allows the channel characteristics to be altered easily and rapidly on a relative scale. Also stream discharge is intermittent which allows the investigator to observe first hand the effects of flowing water on the bed and bank materials in the channel.

Observations of channel materials may be accomplished during seasonal periods when precipitation is low, the ground water table is low and the stream channel is dry. The extensive erosion at the "Big Bend" on the Finney farm and the corresponding loss of acreage is extremely intriguing to anyone interested in the work of streams. The scope of the remainder of this paper will surround the effects of natural channel armouring, the competence of Dry Creek and the corresponding relationship to the changes in channel characteristics that have been observed due to the displacement of the

Fig. 1) View looking west in the channel of the "Big Bend" on 3/30/84, shortly after the spring snow melt and corresponding maximum discharge of Dry Creek. Dark areas of the escarpment are areas of fresh slide material resulting from bank undercutting.

Fig 2) View looking east in the channel of the "Big Bend" on the same date. Maximum height of the escarpment is between 30' to 35' as shown in the upper left hand corner of the picture. The hillside shown in the upper right hand corner of the picture is bedrock.

stream's equilibrium resulting from mining within the channel. More specifically, an attempt will be made to prove that the generalization concerning readjustment through Le Chatelier's principal quoted from Mackin earlier, which may be acceptable under natural conditions, is certainly not a justifiable rule when human stress is applied to a natural stream system. Through an understanding of these problems an attempt will also be made to determine the future course of the Dry Creek channel following the natural progression of the stream to reach equilibrium conditions. Furthermore, an analysis of the corresponding loss of acreage due to bank undercutting and stability of the bank material will be in order.

BANK STABILITY

As a result of the rapid down cutting of the channel of Dry Creek, the majority of the bed load and armouring material has been derived from the channel banks in the area of the Finney farm. This material consists of glacial outwash deposited in the bedrock valleys of this area of Licking County. The outwash material appears to exhibit typical sedimentary characteristics resulting from the work of glacial meltwater streams. The wide variation in the velocity, competence and total discharge with time on a yearly, daily or even hourly basis in these streams results in outwash deposits which are partially stratified and sorted. Stratification and sedimentary structures observed, such as large and small scale cross beds, are fairly regular and are similar to other coarse alluvium but

Fig. 3) Close up of the escarpment of the "Big Bend" in the channel of Dry Creek. The fining upward sequence observable is due to decreasing competence with time of glacial meltwater streams. Poorly stratified sections are observable. Cobble size particles may be described as having fair to good roundness but poor sphericity.

are not as uniform as sedimentary deposits resulting from streams with a more stable average discharge.

Upon first observation of the bank of the "Big Bend", which is approximately 30' to 35' high in the southernmost portion of the bend, one notices the fining upward sequence of the outwash material. This is due to the reduced competence of the meltwater streams as the retreating glacier moved to the north, away from Licking County. Increasing distance from the discharge source (melting ice) and the extreme variability of discharge from this source produced lower competency levels and the fining upward sequence observed. Because this investigation is primarily concerned only with the size of the bed load and armouring material within the channel which was derived from the banks, measurements of representative samples of bank materials were not made. An on sight description would reveal that particle sizes range from clay to boulder sizes with the highest percentage of material included in the sand and cobble size range.

Because the majority of acreage lost on the Finney farm is in the area of the "Big Bend" a question arises concerning the amount of acreage which may be lost in the future even if no more erosion from the stream itself were applied. At this point a quote from Anastasia Van Burkalow, 1945, p. 697, seems quite appropriate:

> "Masses of fragmental material may be produced by fluvial, eolian and glacial deposition. The

> influence of the time factor must not be forgotten. Whatever the origin of the fragmental material and the cause of development of the slope of repose, that slope will be at its maximum steepness only in its youth. Once the addition of material or the undermining or other loss of support ceases, weathering and erosion will begin their work of reducing this slope to a plane."

The slope of the escarpment of the "Big Bend" adheres to this hypothesis. It is now at its maximum steepness and through future time retreat of the escarpment will be seen first at its initial angle of repose, then further and further toward the position of a plane. In terms of geological time there is no fixed angle of repose at which loose material will remain stable, for, given a long enough time, any slope will be reduced, even by weathering and mass wasting alone, to more and more gentle inclinations (Behre, 1933; Heim, 1932; Sharpe, 1938). Of course the magnitudes of geologic time do not concern this investigation, although the erosion at the Finney farm has occurred in such an accelerated manner, due to both the unconsolidated nature of the channel material and the human stress factor, that these processes must be brought forth in order to estimate the amount of acreage which will be lost over the next 25 to 50 years.

Fig. 4) Fresh slide material in the channel of Dry Creek. The slope of this material is 42 to 46.5 degrees (measured with a Brunton compass) which may be considered as the initial angle of repose for the unconsolidated glacial outwash material.

Fig. 5) Comparison of slope angles of fresh slide material and remnant slope of the escarpment may be made in the right hand section of the picture. Remnant slope angle is 64 to 66 degrees (measured with a Brunton compass). Notice the lack of talus material at the base of the escarpment due to the action of the high water at peak discharge. The only talus material is due to recent slide material deposited after the high water level receded.

STREAM COMPETENCE

In order to evaluate the effects of natural channel armouring in the channel of Dry Creek, an analysis of the competence of the stream must first be accomplished. Competence is the measure of a stream's ability to transport a certain maximum grain size of sediment (Bloom, 1978). Bloom (1978) further explains that competence depends primarily on velocity of the stream, although channel slope, the shape and degree of sorting of the sediment particles, amount of suspended load and water temperature can also affect competence.

Perhaps in more detail, D. F. Ritter (1978) explains that two hydraulic factors have been utilized to represent the flow condition in the competence relationship. The first, critical bed velocity, is used to demonstrate the obvious fact that the eroding and transporting power of a river expands repidly with an increase in velocity at the channel bed. Because of the hydraulic resistance and turbulence produced by the roughness of the channel bed, the maximum velocity in natural streams is maintained, not at, but near the water surface. In the channel of Dry Creek, cross sectional area is relatively wide in comparison with discharge and stream flow is shallow. These geometric relationships result in bed velocities which are greater than those observed in a narrower channel with equal discharge. By widening its channel, Dry Creek has produced higher bed velocities and an increase in stream competence. For the purpose of this examination the average velocity of Dry Creek at peak discharge will be substituted for bed velocity. Determination of the average velocity will be achieved through the use of the Manning equation:

$$V = \frac{1.49\ R^{2/3}\ S^{1/2}}{n}$$

where V is average velocity, R is the hydraulic radius, S is the slope and n in the Manning number for bed roughness.

The second factor, acknowledged by Ritter (1978), critical shear stress, signifies the downslope component of the fluid weight exerted on a bed particle. It is proportional to the depth - slope product and can be expressed by the DuBoys equation for boundary shear:

$$\tau_c = \gamma\ R\ S$$

where τ_c is the critical shear stress, γ the specific weight of the water, R the hydraulic radius and S the slope. This stress is viewed as the amount of stress supplied by the stream in order to begin the entrainment process. The results of the measured critical shear stress and stream competence can be reviewed as follows by Ritter (1978): "The processes of entrainment determine the type and magnitude of erosion that occurs on the channel floor. It is incorrect, though, to assume that the only significant erosion is vertically directed." This thought will be considered again as the effects of natural channel armouring are examined.

In order to satisfy the Manning equation it is very important that the value for bed roughness (Manning's n) is assigned as accurately as possible. The difficulty of this

Fig. 6) Enormous change in channel width may be determined from parallel orientation of logs resulting from the work of the stream at maximum discharge. High water marks were observed where dried foliage has been flattened down by flowing water. These marks were also used in determining hydraulic radius of the stream at maximum discharge.

Fig. 7) Above photo shows evidence of bank undercutting at peak discharge after snow melt. High water marks for determination of hydraulic radius of stream were found from close observation of these fresh undercuts.

task may be quite complex to the beginner. The method used in this survey was to compare the stream geometry and flow characteristics of Dry Creek to published material which presents descriptive data, photographs, longitudinal profiles and cross sections concerning stream channel geometry. In particular, reports by H. H. Barnes Jr. (1967) and Simons and Richardson (1963) were very helpful. Barnes explains the difficulty involved in determining values for bed roughness: "All hydraulic computations involving flow in open channels require an evaluation of the roughness characteristics of the channel. In the absence of a satisfactory quantitative procedure this evaluation remains chiefly an art. The ability to evaluate roughness coefficients must be developed through experience." This investigator found Barnes' explanation to be quite veritable and undisguised. Many times the evaluation of bed roughness can be no more than a guess. Proper selection of the roughness coefficient surrounds a complete understanding of the mechanics and principles of hydraulics and the conditions of open channel flow.

By observing and comparing ripple patterns, bed forms and bed particle sizes a selection for the roughness coefficient (n) in the area of the "Big Bend" was estimated to be 0.024 ($ft^{1/6}$). This figure was selected because in the reach of the "Big Bend" the stream channel is very clean of vegetation and moss growth and although sinuosity plays an important role in roughness determination, the radius of curvature of the "Big Bend" is so much greater than channel width that this factor does not carry significant importance to the evaluation. Upstream from the "Big Bend" reach, the roughness coefficient was evaluated to be even lower (0.017) because bed material consists mainly of sand rather than cobble size particles.

The remaining variables needed to evaluate the stream velocity through the use of the Manning equation are slope and hydraulic radius. In determining the slope of the channel of Dry Creek, three sources of data were available: the U.S.G.S. $7^{1/2}$ minute Newark Quadrangle, a computer printout of elevations compiled from aerial photos by Henderson Aerial Surveys Inc. and a plan view contour map also produced by Henderson Aerial. By comparing these three sources with each other and with an aerial photograph dated 3/30/83, it was determined that the plan view contour map compiled by Henderson Aerial was the most accurate source for elevation points. Channel length or distance on the Finney property was also measured from the same aerial photograph mentioned above. This distance was checked by measurements taken from the U.S.G.S. Newark Quadrangle and a discrepancy of only 6' was found. Some change in the slope of the channel can be expected at the present date, but this change can be considered negligible for the purpose of this investigation.

$$\text{slope} = \frac{\text{change in elevation between boundaries}}{\text{length of channel between boundaries}}$$

Change in elevation on the Finney property in 1983 is:

892' - 863' = 29'

Length of the channel on the Finney property in 1983 is:

4217' as measured from aerial photo.

$$\text{slope} = \frac{29'}{4217'} = 0.0069$$

The value for the hydraulic radius (cross sectional area divided by the wetted perimeter) was measured on site by observing high water imprints on the banks of the channel. Channel width and depth were measured across a section of the "Big Bend" reach where water depth at maximum discharge and channel bed form appeared to be fairly uniform. A Brunton compass leveled in the line of sight of the high water imprints across the channel and a depth stick were employed in the measurement of the average water depth of the stream at peak discharge. Measurements were as follows:

channel width	average channel depth	cross sectional area	wetted perimeter
91 ft.	3.36 ft.	305.76 ft.^{2}	97.72 ft.

$$\text{hydraulic radius (R)} = \frac{305.76}{97.72} = 3.13 \text{ ft.}$$

Determination of the average velocity of Dry Creek during maximum discharge:

$$V = \frac{1.49\ R^{2/3}\ S^{1/2}}{n} = \frac{1.49\ (3.13)^{2/3}\ (0.0069)^{1/2}}{0.024} = 11.02 \text{ ft/s}$$

11.02 ft/s (0.305 m/ft) = 3.36 m/s = 336 cm/s

Determination of critical shear stress (tractive force) of Dry Creek during maximum discharge:

$$\tau_c = \gamma\ R\ S = 62.4\ (3.13)\ (0.0069) = 1.35 \text{ lbs/ft} \quad ft^2?$$

Because stream competence is primarily dependent on velocity, the calculated value of average velocity at the maximum discharge of Dry Creek during the spring snow melt re-presents the time when competence is at its highest level and therefore the stream has its maximum capability to erode its channel. The force with which a running fluid influences its bedding, causing erosion and transport of any material there, depends upon the qualities and velocity of the fluid (Hjulström, 1935). Also, because the head of this investigation is directed towards the effects of channel armouring on the rate of horizontal bank erosion versus vertical bed erosion, it is necessary that the relationships between bed velocity and average velocity is brought forth. As Hjulström (1935) suggests from his studies relating kind of material (size) and minimal erosion velocity:

> In order to express the relationship mentioned it is necessary first to more clearly define the variables, the velocity and kind of material. As far as the speed is concerned it would certainly, to obtain an exact result, be necessary to have a whole curve or formula stating the variation of the velocity according to the height above the bottom. As such a diagram is never obtainable it would certainly be preferable to use the bottom velocity. But this is only stated in a limited number of cases, and is more difficult to decide than the surface and average velocity. For these reasons the average velocity has been made use of, it being presumed that this is 40% greater than the bottom velocity. This percentage depends inter alia upon the depth, but it has been presumed that this exceeds one meter.

The author of this paper feels that the 40% decrease from average velocity to bed velocity is a bit ambiguous when applied to the flow characteristics of Dry Creek. Even at peak discharge, the average depth there is only 3.36 ft., which is very close to the minimum standard set by Hjulström of 1 meter and may have an erroneous effect on his evaluation of a 40% decrease from the average. Furthermore, the type of flow in the channel must be considered. By evaluating the Reynolds number for laminar or turbulent flow it is evident that at peak discharge the flow of Dry Creek is quite turbulent:

$$Re = \frac{vd}{\nu}$$

where Re is the Reynold's number, v is the average velocity, d is the average depth and ν is the kinematic viscosity. The calculation for Dry Creek is as follows:

$$v = 11.02 \text{ ft/s } (0.305 \text{ m/ft}) = 3.36 \text{ m/s}$$

$$d = 3.36 \text{ ft } (0.305 \text{ m/ft}) = 1.025 \text{ m}$$

$$\nu \text{ for water at 20 degrees centigrade} = 1.007 * 10^{-6}$$

$$Re = \frac{3.36\ (1.025)}{1.007 * 10^{-6}} = 3.42 * 10^{6}$$

From experimental studies, Osborne Reynolds made the following observations:

If $Re < 2000$, the flow is laminar
$2000 < Re < 4000$, the flow is transitional
$Re < 4000$, the flow is turbulent

The mixing of water, characteristic of turbulent movement, tends to equalize the different velocities at different depths. At the transition from laminar to turbulent movement a mixing process begins, whereby the water particles from various levels and with very different velocities are brought together and then move with a medium velocity. The whole water - mass thus becomes so to speak, interlinked (Beyerhaus, 1916).

In lieu of the effects of turbulence, the average velocity as calculated using the Manning equation will be used for competence relationships.

It was the original aim of this section of the investigation to relate velocity to the D_{50} and D_{90} grain sizes* in the armouring layer by using the Hjulström curve to determine a transport classification of active or inactive for the bed material of Dry Creek at peak discharge. However, upon review of the velocity value already determined and an approximation of the D_{50} and D_{90} values for the bed material, it has been discovered that these values exceed the limitations provided by the graph. This discovery lead to further research to produce a viable relationship between velocity and size of bed material to give competence results. This research has produced a listing of maximum permissible velocities and corresponding tractive shear force values determined experimentally by Fortier and Scobey (1926), which are recommended for the design of open channels by Ven Te Chow (1959). The maximum permissible velocity, or the nonerodible velocity, is the greatest mean velocity that will not cause erosion to the channel body (Chow, 1959). In relation to this investigation the channel material classification chosen as described by Fortier and Scobey is that of cobbles and shingles. From their evaluations a maximum permissible velocity of 6.50 ft/s and a corresponding critical shear stress of 1.10 lbs/ft^3 is allowable. From the results of this investigation which include a velocity of 11.02 ft/s and a critical shear stress in the order of 1.35 lbs/ft^3, it is clearly evident that the bed material in the Dry Creek channel is in a state of active transport during periods of maximum discharge.

*The D_{50} and D_{90} grain sizes are representative values for relative bed material sizes. For example, the D_{90} value specifies that 90% of the bed material is smaller than this size.

BANK vs. BED EROSION

Originally, it was theorized that rapid erosion and increasing radius of curvature of the "Big Bend" in the channel of Dry Creek may have been related to the streams inablilty to erode the channel bed material in a vertical fashion in order to adjust the stream gradient. Now, through the evaluation of available stream velocity and shear stress, it is evident that this is not a viable theory and that the stream is deepening its channel on the Finney property in order to readjust the stream gradient. Although, because the graded stream is a system in equilibrium which adheres to the basic laws of physics, including the principle of least work, it is evident that the work of gradient readjustment has been performed most conservatively in a manner which has resulted in more dramatic horizontal, rather than vertical changes in channel shape (channel length vs. channel depth).

The armouring material in the channel is residual material, it has already been preferentially differentiated due to the action of the flowing stream. From observations made in the channel during low discharge, the cobble and blade shaped clasts form a tightly fitting pavement or armouring layer. This is a compositional feature which has resulted through particle to particle contact as stream energy has not reached the critical tractive force necessary to entrain the clasts, but has provided the required energy to shift the clasts into a position which presents a smaller cross sectional area to the flow. The observed orientation produces less surface area

Fig. 8) Example of the armouring material at the east section of the "Big Bend". Parallel orientation of the long or A axis of the blade shaped particles positions the intermediate axis parallel to the flow during peak discharge. This orientation reduces frictional losses from the flowing water.

Fig. 9) Close up of armouring material in the Dry Creek channel. A wide range of size fractions are included in the armouring layer.

and less frictional losses from the flowing water. This armouring characteristic is reviewed through experimentation by T.J. Day (1981): "Concurrent with the development of orientation and dip characteristics, the composition of the surface layer changed from a nearly uniform distribution of particle shapes, to one dominated by disk shapes. Spheroidal particle shapes appear to be more preferentially transported off the bed, presumably as they are more difficult to stabilize, leaving a higher percentage of disk and blade shapes." The packing of noncohesive sedimentary particles on a stream bed can lead to significant differences in the restraint exerted by neighboring grains on an individual particle at the time of entrainment (Yalin, 1972). Noncohesive bed materials can sometimes exist in a dialated or "quick" state that leads to entrainment at low shear stress. In contrast, imbricated cobble - bed streams present an artificially smooth boundary that resists entrainment (Baker and Ritter, 1975).

Even though this material is active, it is only active during periods when the stream's energy level is at its peak. These periods of peak energy are the only times when the stream has the ability to scour the channel bottom, producing a decrease in the channel gradient. Otherwise, the stream has shown a tendency to erode the channel banks which requires less energy, but increases the channel length and also produces a decreased gradient. The energy requirement for bank erosion is less, firstly because all size fractions are incorporated in the bank material which may be transported much

Fig. 10) View of the escarpment in the southern portion of the "Big Bend". Bank undercutting is quite evident. Some sorting and stratification in the escarpment is observable in the background.

more easily than the bed material, and secondly due to the added energy component of the force of gravity working on the stability of the bank material. These two factors, the first extracting less energy from the stream system, and the second adding energy to the system, have resulted in erosive processes in the area of the "Big Bend" which have produced greater horizontal rather than vertical erosion in order to readjust the channel gradient.

Through the examination of transects of the Dry Creek channel compiled by H.R. Finney in 1983, it is evident that there is a great change in the erosive processes of the stream beginning at the easternmost section of the "Big Bend". Finney's calculations show that the channel has deepened approximately 20' in this section from 1962 to 1983. From this information, one must conclude that in nearing the settlement pits, which act as the local base level, the velocity of the stream increases, which in turn has augmented stream competence. The ability of the stream to scour the channel bed has increased greatly, allowing the channel to deepen. It must also be mentioned that bank erosion in this section of the channel is also considerable and in no way is the vertical erosion greater than horizontal erosion. The readjustment of the channel gradient is primarily attained through lengthening of the channel.
The channel geometry is not undergoing adjustments in order to increase velocity and therefore the competence to transport the coarse bedload in the channel, but rather to decrease

the slope and velocity in the development of a gradient that will provide the necessary velocity to transport the suspended sediment load supplied from the entire drainage basin.

A significant control related to the problem at Dry Creek which the writer failed to mention earlier, is the construction of an earthen dike built by the residents of the property adjacent to the Finney farm. This dike was built at the east end of what is now the "Big Bend". The construction of this structure diverted the flow in a meandering section of the channel. The new flow path resulted in a channel length which was shortened by approximately 1444'. As a result the stream gradient and velocity were increased, and consequently, erosion on the Finney property was accelerated. Another factor which may have influenced erosion of the Dry Creek channel is an increase in discharge within the channel. This could result from development af the watershed upstream from the Finney property. Construction in this area could result in a larger catchment area, greater overland flow due to clearing of the vegetative cover or from man-made drainage ditches, etc.. Also, any changes, alterations, or diversifications in weather patterns over the watershed of Dry Creek within the last 30 to 40 years could result in additional stream discharge. Although, it must be stated that during this investigation, no significant development in the area of the watershed was observed. In addition, it is very unlikely that changes in weather patterns have been of the magnitude to cause the considerable erosion that has resulted in the channel of Dry Creek.

THE FUTURE OF DRY CREEK

It is the conclusion of this investigation that the substantial erosion observed on the Finney farm is the direct result of the collaborative effects of both channel mining procedures and the construction of the protective dike in the channel of Dry Creek. These erosive processes have been generated by the stresses men have induced on the stream which was once flowing in a state of equilibrium in a graded system. The inherent and profound potential of the stream is seen in the capacity it has shown to readjust channel geometry and characteristics in a way which will eventually check and balance the stresses applied by man. It is apparent to this investigator that channel characteristics are being modified in a way which will decrease, not increase, slope and velocity, and the stream will one day establish a stable energy system comparable to the equilibrium state before channel mining began. The sooner sand and gravel mining within the channel is ended, the sooner the stream will be able to stabilize. The destruction of the Finney property is already consigned. The erosion at the "Big Bend" will most likely migrate to the south where the resistance of the bedrock hill will retard the work of the flowing water and redirect the energy in areas upstream. Landowners upstream from the Finney property and adjacent to the stream channel may be seeing the effects of this energy within the next 5 or 10 years.

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